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(NASA-CR-[illegible]) USER'S MANUAL FOR THE ALS BASE HEATING PREDICTION CODE, VOLUME 2 (Remtech) 30 p

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FOREWORD

Preparation of the code included many contributors. The users interface was prepared by Darren Abbott and Michael Fulton; the convection routines were designed and coded by Robert Bender, Daniel Haynes, Anthony Saladino and Maurice Prendergast; and the plume radiation routines were designed and coded by Michael Fulton and John Reardon. James Levie furnished valuable consultation on the UNIX and X Window System operating environments.

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Section 1
INTRODUCTION

The ALS Base Heating Prediction Code is based on a generalization of first principles in the prediction of plume induced base convective heating and plume radiation. It should be considered to be an approximate method for evaluating trends as a function of configuration variables because the processes being modeled are too complex to allow an accurate generalization.

The convective methodology is based upon generalizing trends from four-nozzle configurations, so extension to use with strap-on boosters, multiple nozzle sizes, and variations in the propellants and chamber pressure histories cannot be precisely treated.

The plume radiation is more amenable to precise computer prediction, but simplified assumptions are required to model the various aspects of the candidate configurations. Perhaps the most difficult area to characterize is the variation of radiation with altitude. The theory used in the radiation predictions is described in more detail in Ref. [1].

This report is intended to familiarize a user with the interface operation and options, to summarize the limitations and restrictions of the code, and to provide information to assist in installing the code. The following sections address these topics.

Section 2
USER'S INTERFACE

The user's interface is handled by a set of windows in which the user can interactively construct a problem or assign files from a previous problem to rerun or modify. The windows are operated using the usual window manipulation techniques. The mouse is used to position the pointer in the button area for each displayed function. If it is a simple button (no triangle), a select (left mouse key) will cause the selected function to occur. If the function button has a triangle displayed, as illustrated in Fig. 1, a menu can be pulled out in the direction of the triangle by dragging the cursor using the right mouse key. The selection from the menu is highlighted as the cursor crosses it, and the highlighted item is selected when the right mouse key is released. Making some selections excludes others, so the excluded selections appear dimmed and cannot be selected.

All windows except the CONTROL WINDOW appear with tacks in the upper left, so they will remain until untacked by selecting the tack with the mouse. As with other windows, a select in the upper window boundary will cause it to come to the front, and it can be dragged to another location while depressing the select (left) mouse key.

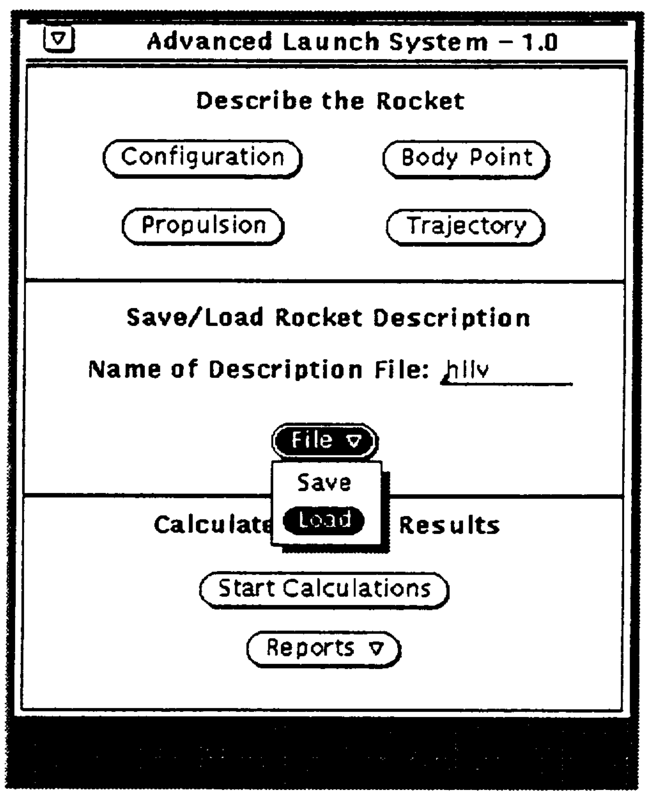


Figure 1: Illustration of the Control Window for the Advanced Launch System (ALS) Base Environment Prediction Code

The entry fields provided on the interface windows are selected by selecting the field using the cursor and the left mouse button, but in entering a sequence of fields, a carriage return will move the cursor to the next field. Although some functions of the code may appear to respond to entries as they are made in entry fields, a carriage return must be made to assure the entry is recognized by all functions in the code.

A field can be cleared by selecting the entry and striking the space bar. The entry is selected by placing the mouse pointer in the field and using a quick triple click on the left mouse button or wiping the pointer over the entry while holding down the left mouse button.

2.1 Input Operation

When the program is executed, the CONTROL WINDOW and the VIEW PROJECTIONS WINDOW, Figs.1 and 2, appear. Initially, the VIEW PROJECTION WINDOW will be blank, but as a configuration is entered, the projections will be displayed. The illustration of the CONTROL WINDOW in Fig. 1 shows a parameter file "hllv" describing a previous session being loaded. When an existing configuration is loaded, the projections appear in the VIEW PROJECTION WINDOW and the problem can be rerun or modified. If changes are desired they may be made on the input windows described below, and the new configuration can be saved using the first selection under the "file" pull-down menu. It may be saved under the original name in the Description File field or the name may be changed to make a new set of configuration parameter files. The configuration parameter files use the filename entered with extensions of .bdy, .cfg, .pro and .trj.

When entering a new configuration or making changes in the problem parameters, four sets of windows are used as indicated by the button areas illustrated in the upper half of the CONTROL WINDOW in Fig. 1.

2.1.1 Configuration Specification

The ROCKET CONFIGURATION WINDOW, Fig. 3, allows specification of the vehicle geometry. This includes the stage dimensions and the engine arrangements. A descriptive title can be entered to identify the configuration in the resulting output files. Below the title, a toggle is provided to select either inches or feet as units to be used for linear dimensions.

The vehicle geometry is defined in a right-hand, Cartesian system with the X-axis on the centerline of an axially symmetric main stage. The Z and Y axes are shown in the VIEW PROJECTIONS WINDOW. The X-axis origin is fixed by specifying the main-stage nozzle exit station, and other X dimensions are referenced to this. In this initial version of the code, it is required that the booster exit plane be at the same axial location as the main-stage exit plane.

Fields are provided to describe the stage forebody diameters and lengths. These should be entered beginning at the top, but unused dimensions can be left blank. The entry fields for the vehicle dimensions are adequate for the expected size of advanced vehicles, but if the fields overflow because of entry errors, an overflow indicator will

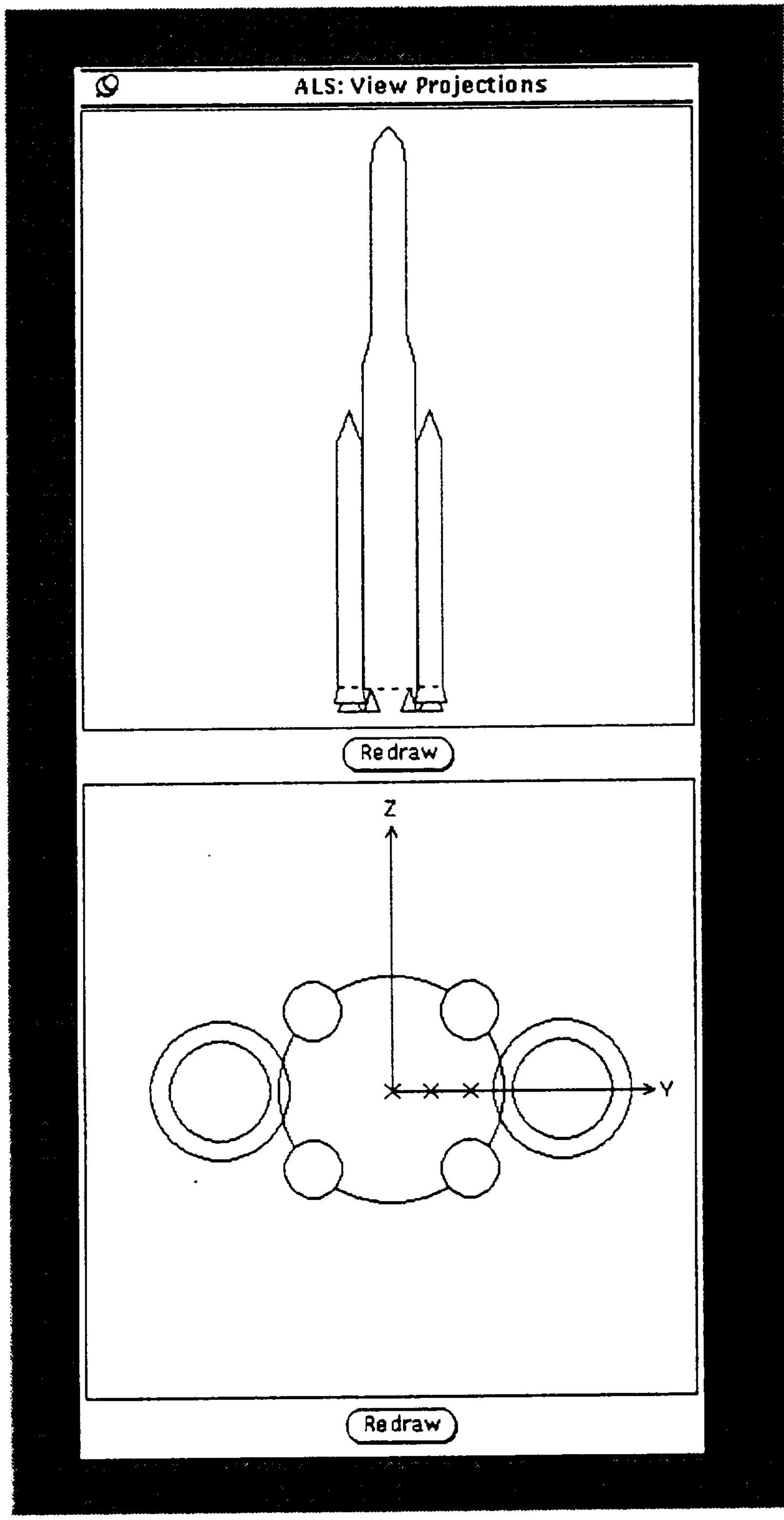


Figure 2: Illustration of the ALS:View Projection Window

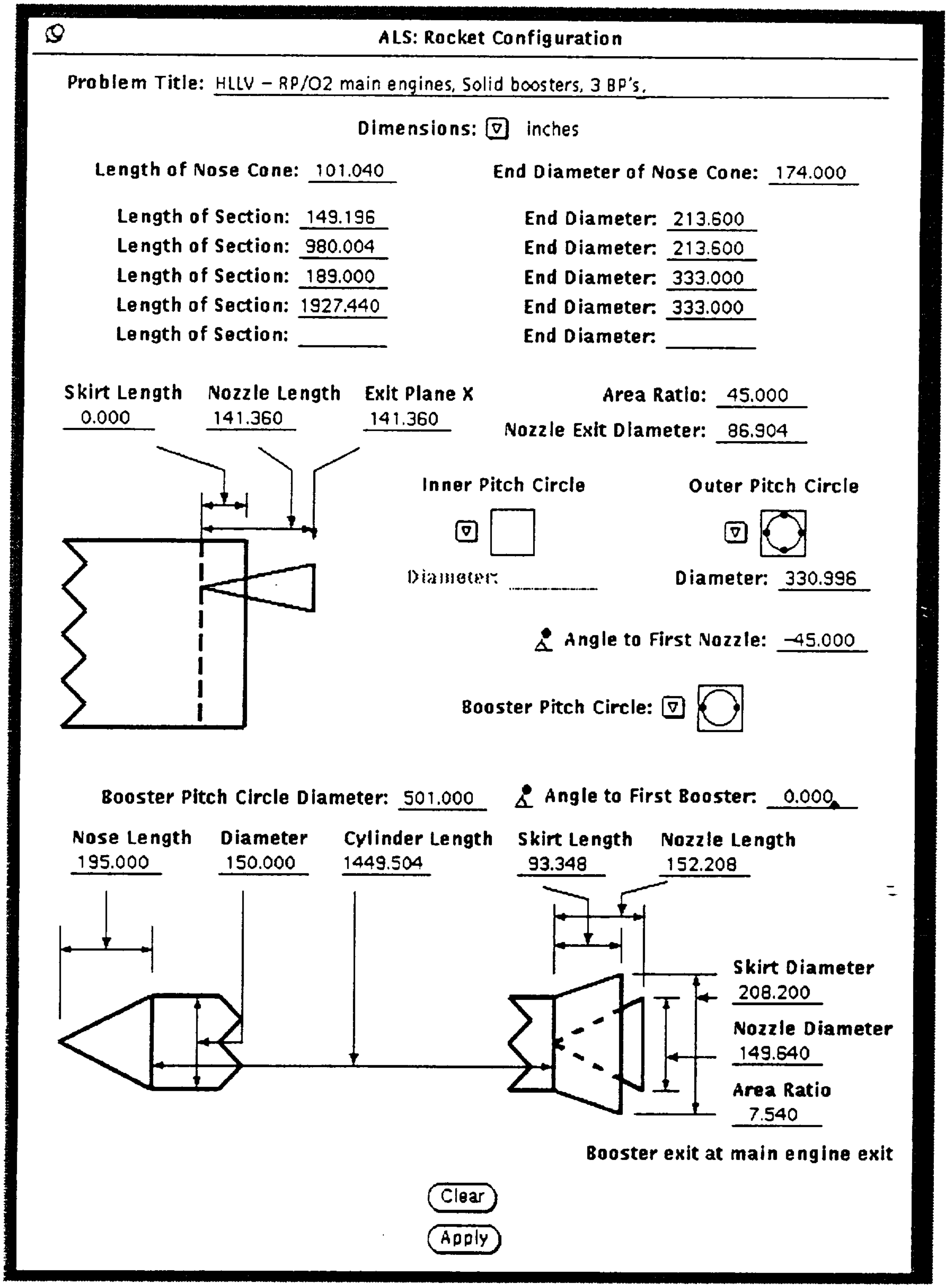


Figure 3: Illustration of the ALS:Rocket Configuration Window

appear. The overflow indicator is illustrated in the Total Thrust field of the PROPULSION SYSTEM SPECIFICATION WINDOW in Fig. 4. The dark triangle pointing to the right indicates additional digits to the right which can be observed by selecting this field with the mouse and moving to the right using the keyboard arrow. As the digits are recovered from the right and overflow on the left, the overflow indicator shifts to the left end of the field.

Following the forebody dimensioning, the user moves to entry fields defining the Skirt Length for a cylindrical skirt aft of the base heat shield, the Nozzle Length and the X-coordinate of the (nozzle) Exit Plane. The "Nozzle Length" specified for both the Main Stage and the Booster is not the actual length of the nozzle, but represents the dimensions illustrated in the ROCKET CONFIGURATION WINDOW. On the Main Stage, this is the dimension from the nozzle exit to the base heat shield, while on the Booster, it is the dimension from the nozzle exit to the forward end of the skirt.

The Main-Stage engines are arranged on an inner and outer pitch circle, and the number of engines in each circle is specified by pull-down menus specifying 0, 1 or 2 engines in the inner circle and 0, 3, 4, 5 or 6 engines in the outer circle. Multiple engines in each circle are evenly spaced on the specified circle diameter. If two engines are chosen for the Main-Stage inner circle, they are constrained to locations on the Y axis,

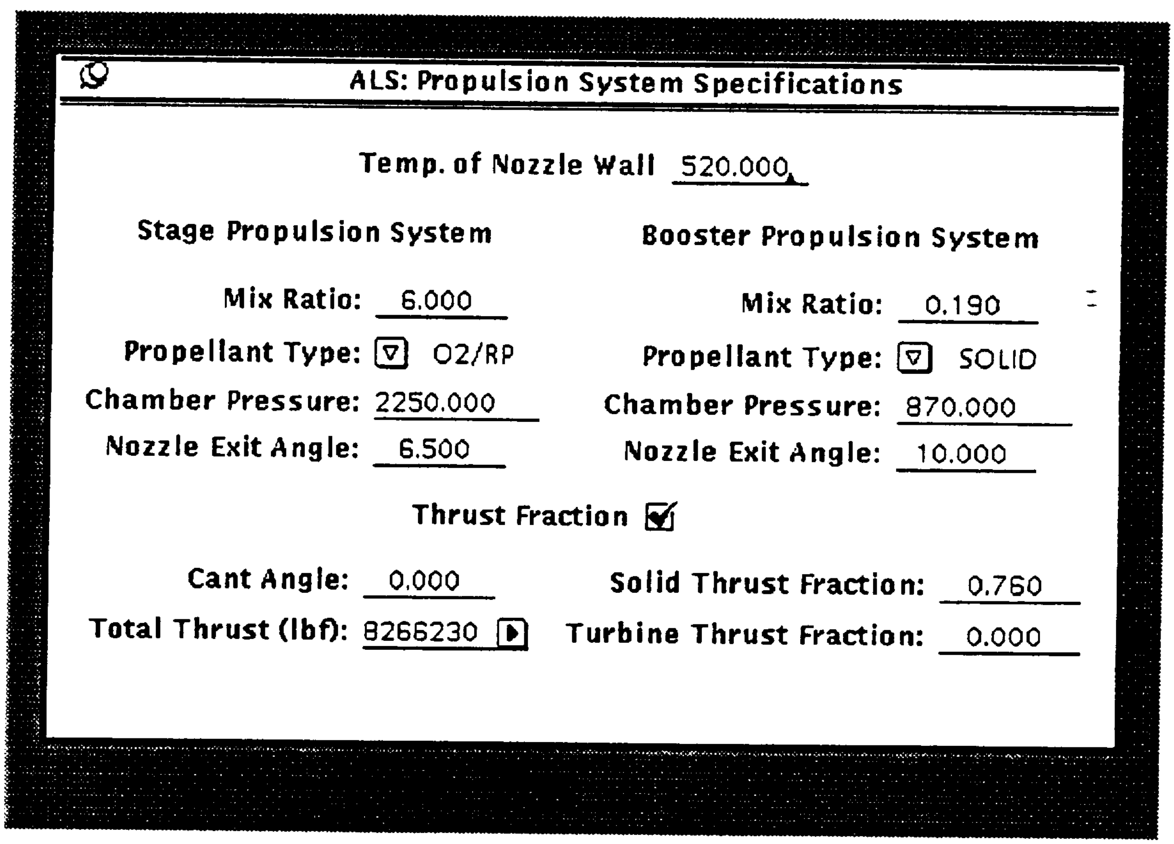


Figure 4: Illustration of the ALS:Propulsion System Specification Window

so that they will always be apparent in the elevation projection. The relative alignment of the Main-Stage, outer-engine circle is provided by the input angle to the first nozzle. The nozzles are numbered counter-clockwise, and the angle to the first nozzle is measured from the Y toward the Z axis.

Selection of 0, 2, 3 or 4 strap-on boosters is made using the pull-down menu for the booster pitch circle specification, the pitch circle diameter, and the angle to the first booster. The strap-on configuration dimensions provided are for a cylindrical booster with a flared skirt. Use of a cylindrical skirt or tapered boat-tail is not allowed in the current assumptions for handling the surface geometry.

Although only strap-on boosters are specifically defined in the code logic, configurations in which a number of the Main-Stage engines are used for boost can be handled by splicing together results for two configurations with the booster trajectory modified to give cut-off at separation.

The Apply button at the bottom of the window is an artifact of an earlier plan. In the current code, all changes appear in the VIEW PROJECTION WINDOW as sufficient information is supplied in the ROCKET CONFIGURATION WINDOW. However, the Clear button can be used to clear the window, but this operation is protected by a warning and second selection. As changes are made in the configuration, the scale in both the elevation and aft-end projections is changed to fit the configuration within the projection frame while providing the user with the largest possible display. As a result, the scale of the two views is not usually the same.

2.1.2 Propulsion System Specification

The PROPULSION SYSTEM SPECIFICATIONS WINDOW illustrated in Fig. 4 is used to specify the base wall temperature, the propellant mixture ratio, the propellant type, the engine chamber pressure, and the nozzle-exit angle. The entries for booster cant angle, SRM thrust fraction, total thrust, and turbine thrust fraction were provided for prediction methods which are not used in the current code, so the results will be insensitive to changes in these fields.

The entry in the Temp. of Nozzle Wall field has a default initialization of 520 R. It is used for both the nozzle wall exterior and the base surfaces in preparing the convective heating rate tabular output. However, the actual wall temperature will be a function of the thermal protection system (TPS) design, and the use of a single constant temperature is only intended to provide a simple basis for evaluating convective heating rates. If details of the TPS design are to be evaluated, the user can make a better approximation using the tabulated values of heat transfer coefficient and recovery temperature which are also available in the convection result tables.

Separate propulsion system parameters are provided for the Main-Stage and Booster, but if no Boosters are selected for the configuration, the Booster Propulsion System entry fields will appear dimmed. Propulsion system parameters include: Mix Ratio, to specify the oxidizer/fuel mass ratio for liquid engines or the propellant mass fraction of aluminum for Solid Rocket Motors; Propellant Type, which is selected from a menu list of propellants currently recognized by the code (O_2/H_2, O_2/RP and SOLID); and Chamber Pressure.

The Chamber Pressure entry supplies a single constant chamber pressure to be used for the prediction. If throttling to a lower pressure is desired, the results of separate runs can be spliced together. As stated previously, the Nozzle Angle, Cant Angle and Thrust Fraction entries may be omitted because they are used in a convective heating correlation in the code which is not currently activated. However, the total thrust entry in Fig. 4 illustrates the overflow indicator for the entry fields described in Section 2.1.1.

2.1.3 Body Point Specification

The BODY POINT SPECIFICATION WINDOW illustrated in Fig. 5 provides up to 9 precomputed default locations and spaces to enter locations for 11 more points. Each body point is specified by two locations: the surface location of the point and any point along the surface normal to the point (required by the radiation routines for direction). Coordinates of all the body points are referenced to the X-axis origin represented by the Main-Stage nozzle exit plane. The default body point locations are defined relative to several of the configuration variables, and the indicated positions of these default points will change as the configuration is changed. However, the user locations will remain as defined, so these must be changed by the user if the configuration changes.

The nine default body point locations list only the computed location of the point, and the default surface normal directions are listed in the table below.

Body Points	Default Surface Normal Direction	
1-5	Aft	(Parallel to the X Axis)
6-9	Lateral	(Parallel to the ZY Plane)

The boxes to the left of the default body points are toggled using the left mouse button to select and unselect the location. The points selected will be indicated with a check mark. The default points are located using the conventions in the table below.

Body Points	Default Geometry
1-5	Heat shield between Main-Stage nozzles 1 and 2
6	Booster 1 nozzle exit plane
7-8	Outer Main-Stage nozzle 1 exit plane
9	Inner Main-Stage +Y nozzle exit plane

The intelligence of the default body points specifications is limited, but the locations selected usually conform to a set of critical locations. However, the most critical locations are affected by the engine arrangement. For example, since the heat shield points are arranged between Main-Stage engines 1 and 2, an arrangement such as the HLLV

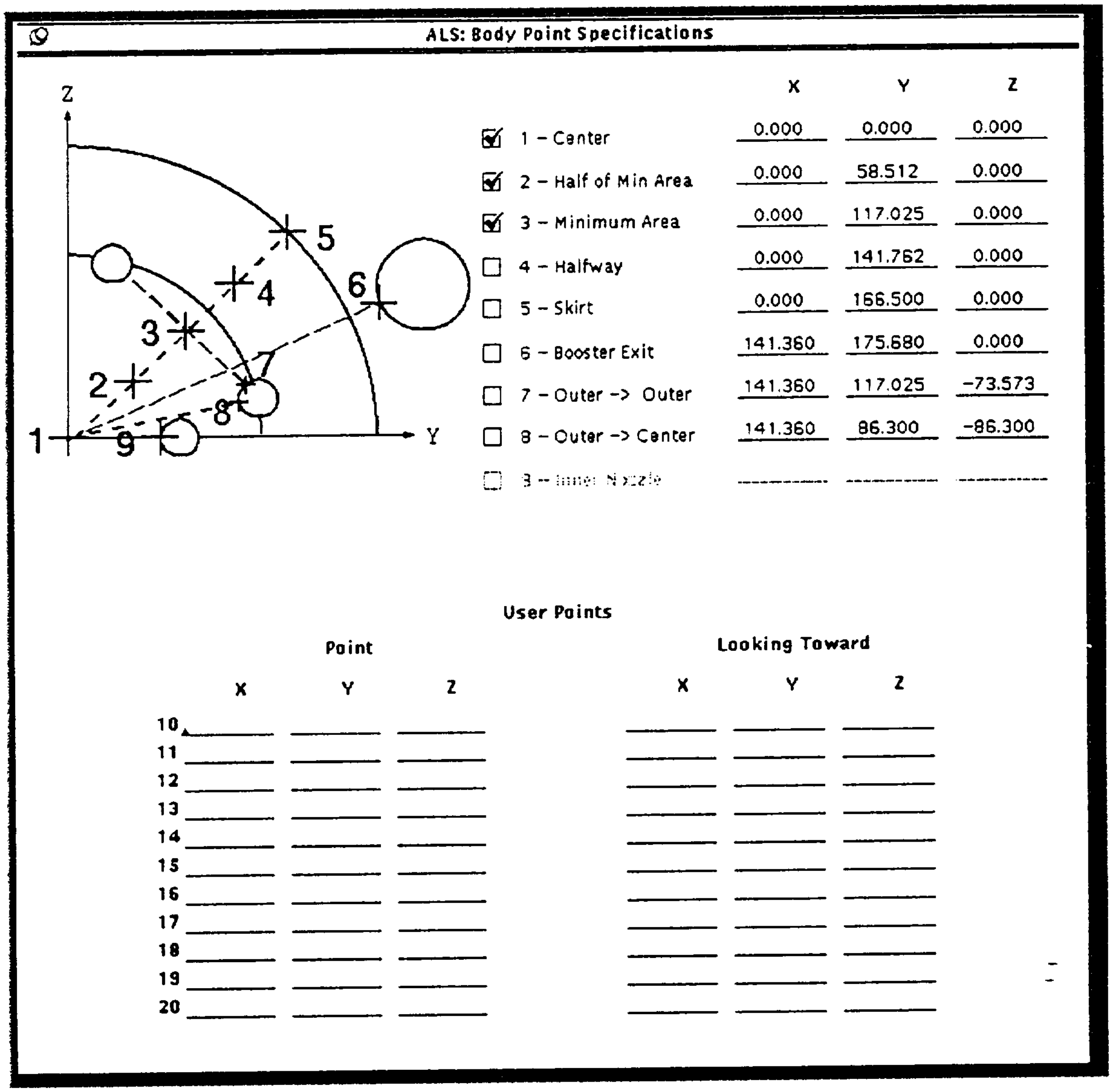


Figure 5: Illustration of the ALS:Body Point Specification Window

example shown in Fig. 2 was set with an initial angle of −45 on the stage engines to align the body points with the booster located at 0 degrees.

2.1.4 Trajectory Specification

A number of trajectories and atmospheric models are furnished using pull-down menus in the TRAJECTORY SPECIFICATION WINDOW, Fig. 6. The menu for the trajectories allows the selection of a user file to specify the trajectory. If user files are defined, it is not recommended that the file extension .trj be used, because the code uses this extension to save selection parameters for the trajectory and atmosphere. In the example shown in Fig. 1, the description file is hllv, so if the data for this case are

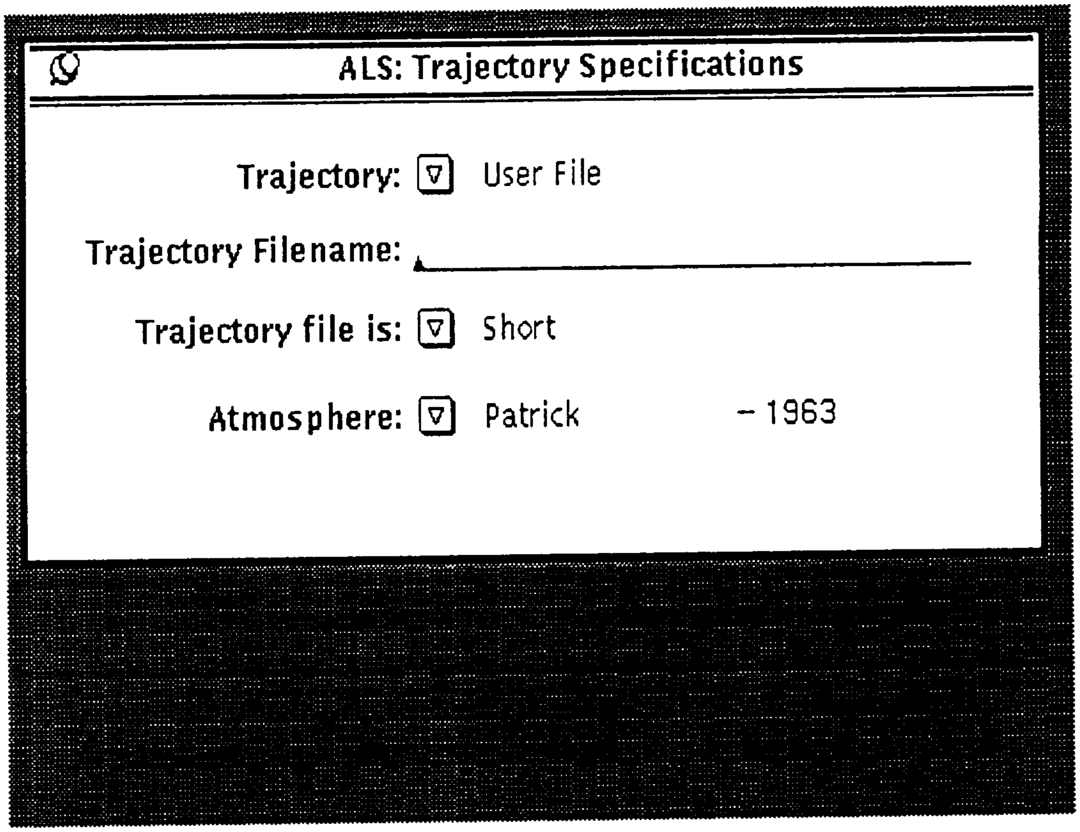


Figure 6: Illustration of the ALS:Trajectory Specification Window

saved for later use, a file named hllv.trj will be produced containing parameters defining the trajectory and atmosphere selected.

If a default trajectory is specified, it is required that the file be in the directory from which the code execution is invoked. The files, listed below, can be copied from the samples directory furnished with the code.

Menu Name	Trajectory Filename	File Format Type
Shuttle	`shuttle_trj`	Long
1.5 Stage	`1_5stage_trj`	Short
Saturn V	`saturn_v_trj`	Short
HLLV	`hllv_trj`	Medium

If a user file is specified for the trajectory, the type of format must be specified using the pull-down menu. The selections and meanings are summarized in the following table.

Record Number	Trajectory Type	Trajectory Parameter	Data Type	Format
1	All	Trajectory Title	character	(a80)
2	All	Variable Count (2, 3, or 4), separation time (sec), Main Engine Cut Off Time (sec)	integer real real	list
3 to EOF	Short	Time (sec), Altitude (feet)	real	list
	Medium	Time, Alt, Booster Pc (psia)		
	Long	Time, Alt, Pc, Velocity (fps)		

Most input routines in the code use the variable count in Record 2 of the file rather than the trajectory type to control input and operation, but artifacts of the original plan for the specification of variables may remain. The use of the variable count in the trajectory file allows a flexible avenue for expanding the trajectory variables in the future.

The atmospheric properties to be used are specified in the TRAJECTORY SPECIFICATION WINDOW using the pull-down menu illustrated in Fig. 7. All of the atmospheric properties are defined by subroutines of the convection code, so no atmospheric data files are required.

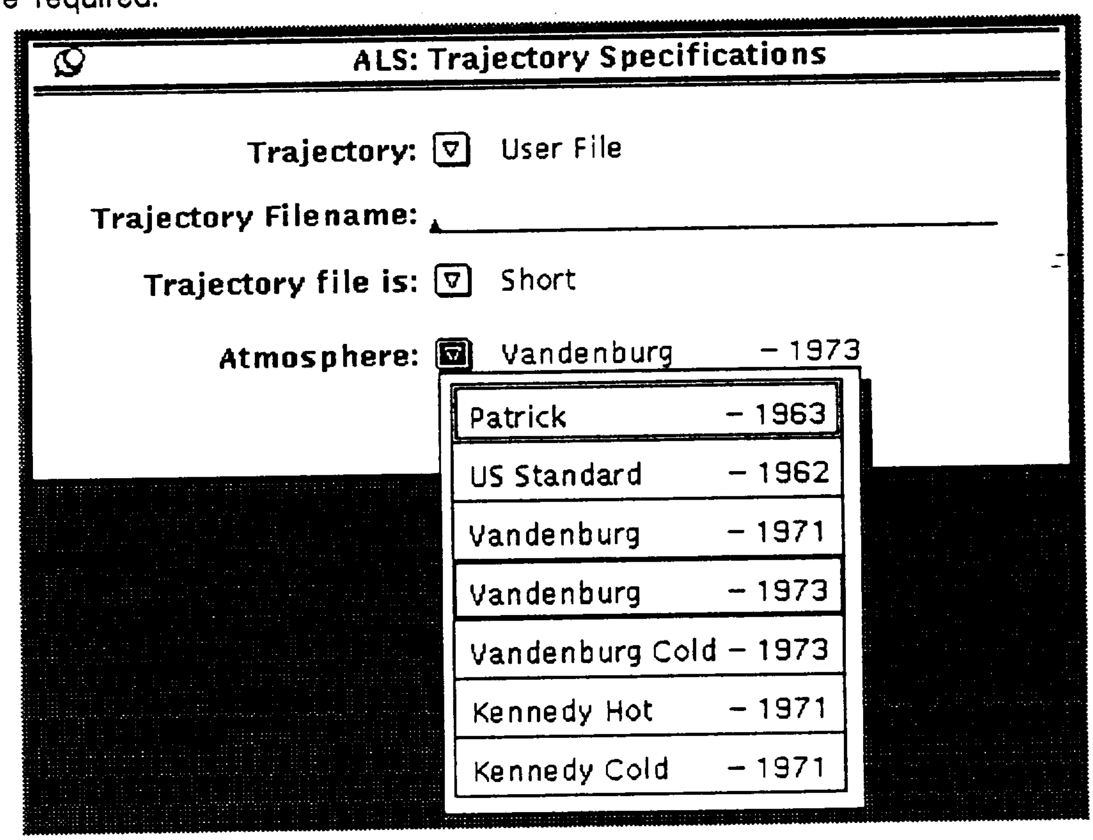


Figure 7: Example of Atmospheric Selection

2.2 Execution and Output Operation

2.2.1 Execution Characteristics

Code execution is begun by selecting the Start Calculations button in the CONTROL WINDOW. During execution, all selections in the CONTROL WINDOW dim except the report button, which allows printing of the input data while the calculation is in progress.

The code produces an interface file, `PSTART.IFC`, for communication of input parameters between the user interface and the convection and radiation codes. The interface file is normally deleted at the successful conclusion of each run, but if an error exit occurs, the file may remain. If an interface file is present, either from a previous run or from an attempt to execute two instances of the code in the same directory, an error message will emanate from the start-calculations button stating that two runs cannot be executed in the same directory. This problem can be corrected by deleting the old `PSTART.IFC` file or moving to a new directory to invoke the second execution of the code.

Execution time of the code will depend upon the configuration and propellants selected. For all propellants except O_2/H_2, the execution is quite rapid, but the band-model predictions (made over a range of altitudes for the O_2/H_2 plumes) require a significant length of time. The time for radiation predictions is affected by the number of plumes and the number of body points selected. The user should keep the window open which was used to execute the code so error messages will be visible. Because the interface code invokes two executable portions, convection and radiation, it is possible for errors to occur which will halt a portion of the code while the selections remained dimmed as the other portion of the code continues.

The progress of longer band-model predictions can be judged by the production of the result files. These files are retained in the current code rather than being deleted to assist in error detection and to provide additional information to the user. The band-model prediction first prepares plume files with filenames in the form

`plu_Re_A/A*_O2_Pc_Pc/Palt.`

If the nozzle area ratio being processed is between two area ratios in the plume library (file `plume_lib` in the data subdirectory), a set of plumes for each area ratio will be produced. A radiation output file will be prepared for each area ratio and each pressure ratio with a filename of the form

`bmp_A/A*_alt-index.`

The user should delete these files as required. In making successive runs with the same nozzle, the plume files will be reused if they are present, but if they have been deleted, regeneration of these files is rapid.

After the band-model predictions are complete, the code rapidly performs the required interpolations and produces the `radiation_tables` output file.

2.2.2 Report Forms

Reports are selected from a pull-down menu at the Reports button as shown in Fig. 8. The selections are Input and Results, and each of these choices can be expanded to the right as illustrated for input in Fig. 8. When one of the Input Report options is selected, a menu corresponding to those on the left of Fig. 9 is displayed. Note that the PROJECTIONS WINDOW has a View Projections button which can be used to display the VIEW PROJECTIONS WINDOW if it has been untacked. The remaining options for both forms of Input Reports are Print and Write-to-File. If the Write-to-File option is selected, the appropriate window shown on the right side of Fig. 9 is displayed for the user to specify a filename.

Although the menu pulled from the Reports/Results button has two selections, Tables and Plots, the Plots selection is not currently available. Selection of Tables produces the display shown in Fig. 10 which can be scrolled vertically using the slider at the right of the display. Display of radiation or convection tables can be toggled with the buttons at the top of the display, and the displayed table can be printed by selecting the Print button.

The printed radiation tables shown in Fig. 11 contain three sections. The first is the radiation from the main-stage plumes. This is followed by the booster plume radiation and the total radiation from both main-stage and booster plumes. The variation in radiation rates is tabulated as a function of trajectory time and altitude, and the integrated loads are

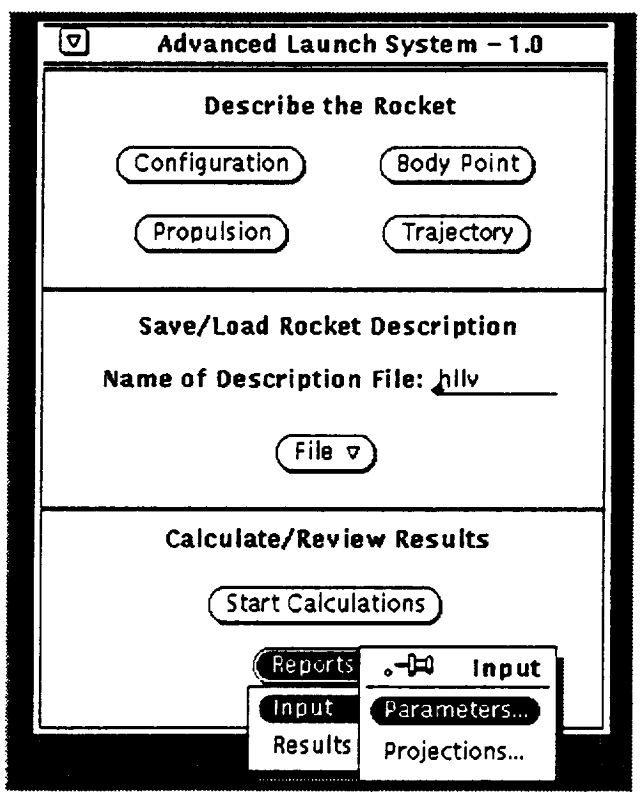


Figure 8: Example of Report Selection

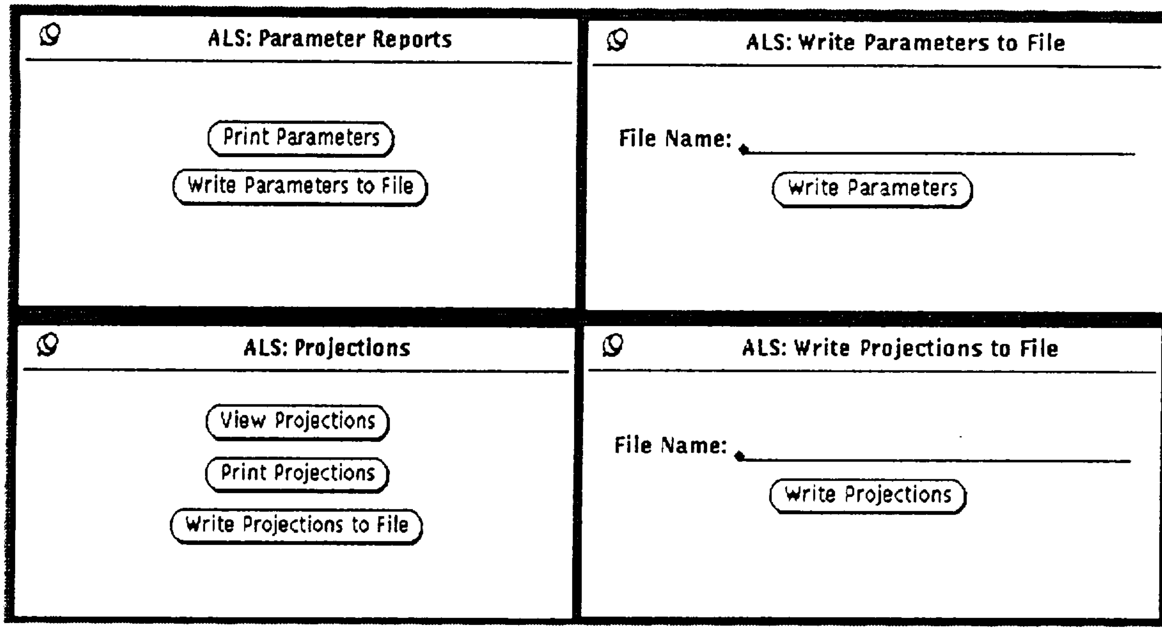
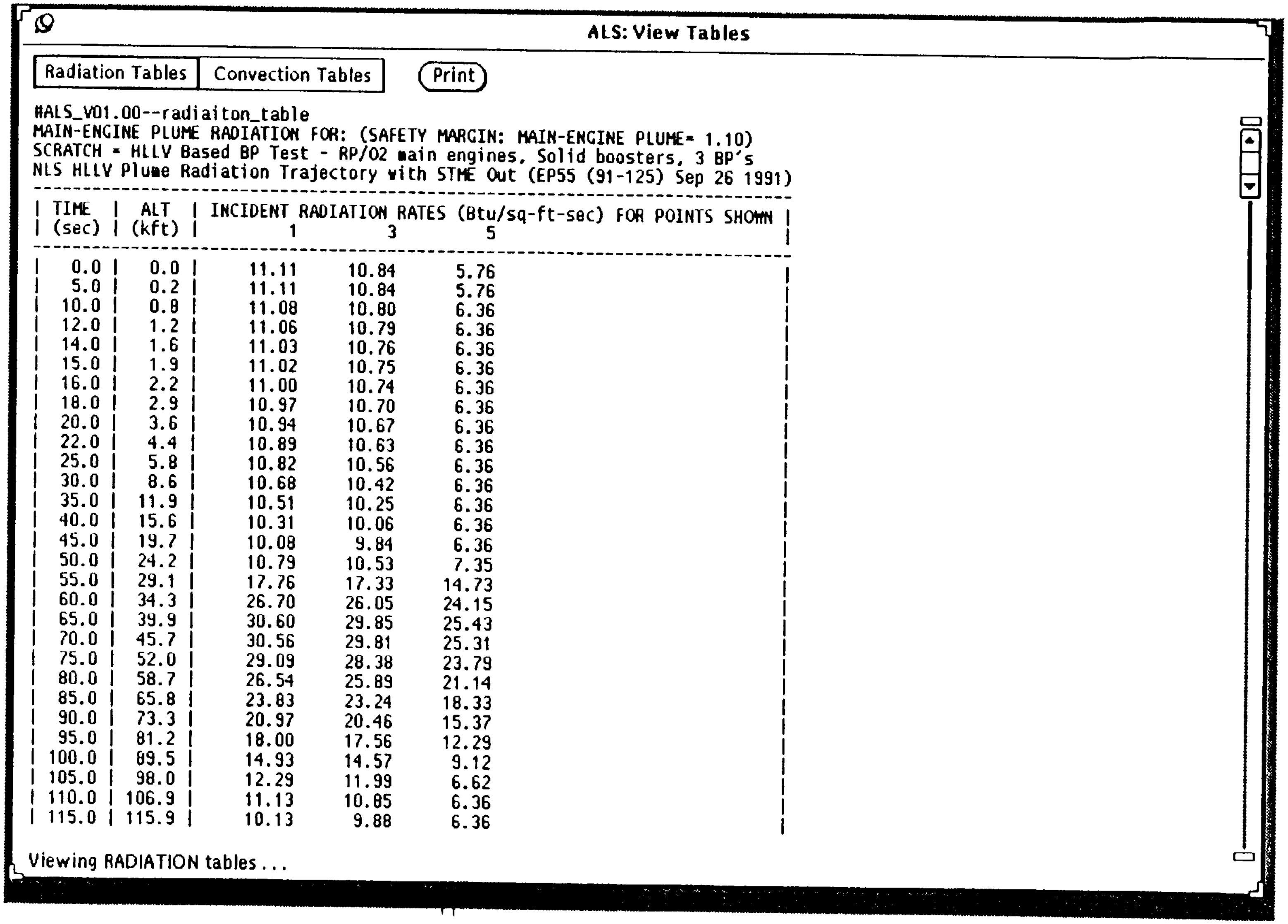


Figure 9: Examples of Format Selection for Input Reports

printed on the last line. The first line in the table heading is required by the code to identify and process the table. This is followed by the title indicating the plume source and safety margin used for the printed output. The next two lines identify the configuration (the title line in the CONFIGURATION WINDOW) and the trajectory used (the first record in the trajectory file).

The printed convection tables are similar to the displayed tables. The first table provides recovery temperature and heating rate as a function of trajectory time and altitude for the wall temperature specified in the PROPULSION SYSTEM SPECIFICATIONS WINDOW. The second table provides recovery temperature and heat transfer coefficients, and both tables contain a final line with the heating rate integrated over the trajectory time.



ALS: View Tables

Radiation Tables | Convection Tables | Print

#ALS_V01.00--radiaiton_table
MAIN-ENGINE PLUME RADIATION FOR: (SAFETY MARGIN: MAIN-ENGINE PLUME= 1.10)
SCRATCH = HLLV Based BP Test - RP/O2 main engines, Solid boosters, 3 BP's
NLS HLLV Plume Radiation Trajectory with STME Out (EP55 (91-125) Sep 26 1991)

TIME (sec)	ALT (kft)	INCIDENT RADIATION RATES (Btu/sq-ft-sec) FOR POINTS SHOWN 1	3	5
0.0	0.0	11.11	10.84	5.76
5.0	0.2	11.11	10.84	5.76
10.0	0.8	11.08	10.80	6.36
12.0	1.2	11.06	10.79	6.36
14.0	1.6	11.03	10.76	6.36
15.0	1.9	11.02	10.75	6.36
16.0	2.2	11.00	10.74	6.36
18.0	2.9	10.97	10.70	6.36
20.0	3.6	10.94	10.67	6.36
22.0	4.4	10.89	10.63	6.36
25.0	5.8	10.82	10.56	6.36
30.0	8.6	10.68	10.42	6.36
35.0	11.9	10.51	10.25	6.36
40.0	15.6	10.31	10.06	6.36
45.0	19.7	10.08	9.84	6.36
50.0	24.2	10.79	10.53	7.35
55.0	29.1	17.76	17.33	14.73
60.0	34.3	26.70	26.05	24.15
65.0	39.9	30.60	29.85	25.43
70.0	45.7	30.56	29.81	25.31
75.0	52.0	29.09	28.38	23.79
80.0	58.7	26.54	25.89	21.14
85.0	65.8	23.83	23.24	18.33
90.0	73.3	20.97	20.46	15.37
95.0	81.2	18.00	17.56	12.29
100.0	89.5	14.93	14.57	9.12
105.0	98.0	12.29	11.99	6.62
110.0	106.9	11.13	10.85	6.36
115.0	115.9	10.13	9.88	6.36

Viewing RADIATION tables . . .

Figure 10: Illustration of the ALS:View Tables Window for Result Reports

```
#ALS_V01.00--radiaiton_table
MAIN-ENGINE PLUME RADIATION FOR: (SAFETY MARGIN: MAIN-ENGINE PLUME= 1.10)
SCRATCH = HLLV Based BP Test - RP/O2 main engines, Solid boosters, 3 BP's
NLS HLLV Plume Radiation Trajectory with STME Out (EP55 (91-125) Sep 26 1991)
```

TIME (sec)	ALT (kft)	INCIDENT RADIATION RATES (Btu/sq-ft-sec) FOR POINTS SHOWN 1	3	5
0.0	0.0	11.11	10.84	5.76
5.0	0.2	11.11	10.84	5.76
10.0	0.8	11.08	10.80	6.36
12.0	1.2	11.06	10.79	6.36
14.0	1.6	11.03	10.76	6.36
15.0	1.9	11.02	10.75	6.36
16.0	2.2	11.00	10.74	6.36
18.0	2.9	10.97	10.70	6.36
20.0	3.6	10.94	10.67	6.36
22.0	4.4	10.89	10.63	6.36
25.0	5.8	10.82	10.56	6.36
30.0	8.6	10.68	10.42	6.36
35.0	11.9	10.51	10.25	6.36
40.0	15.6	10.31	10.06	6.36
45.0	19.7	10.08	9.84	6.36
50.0	24.2	10.79	10.53	7.35
55.0	29.1	17.76	17.33	14.73
60.0	34.3	26.70	26.05	24.15
65.0	39.9	30.60	29.85	25.43
70.0	45.7	30.56	29.81	25.31
75.0	52.0	29.09	28.38	23.79
80.0	58.7	26.54	25.89	21.14
85.0	65.8	23.83	23.24	18.33
90.0	73.3	20.97	20.46	15.37
95.0	81.2	18.00	17.56	12.29
100.0	89.5	14.93	14.57	9.12
105.0	98.0	12.29	11.99	6.62
110.0	106.9	11.13	10.85	6.36
115.0	115.9	10.13	9.88	6.36
120.0	125.0	9.15	8.93	6.36
125.0	134.3	8.19	7.99	6.36
130.0	143.7	7.52	7.34	6.36
133.0	149.2	7.38	7.20	6.36
134.0	151.0	7.36	7.18	6.36
135.0	152.9	7.36	7.18	6.36
136.0	154.7	7.36	7.18	6.36
137.0	156.4	7.36	7.18	6.36
138.0	158.2	7.36	7.18	6.36
139.0	160.0	7.36	7.18	6.36
140.0	161.7	7.36	7.18	6.36
140.3	162.2	7.36	7.18	6.36
144.3	168.8	7.36	7.18	6.36
150.0	178.4	7.36	7.18	6.36
432.6	361.5	7.36	7.18	6.36
MAIN ENG LOADS		4260.88	4156.80	3382.83

Radiation load integration 0.0 to 432.6 sec. Sep time 140.3 MECO 432.6

Figure 11: Example of Printed Radiation Results Tables

BOOSTER PLUME RADIATION FOR: (SAFETY MARGIN: BOOSTER PLUME= 1.25)
SCRATCH = HLLV Based BP Test - RP/O2 main engines, Solid boosters, 3 BP's
NLS HLLV Plume Radiation Trajectory with STME Out (EP55 (91-125) Sep 26 1991)

TIME (sec)	ALT (kft)	INCIDENT RADIATION RATES (Btu/sq-ft-sec) FOR POINTS SHOWN 1	3	5
0.0	0.0	21.76	18.70	7.31
5.0	0.2	22.07	18.97	7.41
10.0	0.8	23.30	20.03	7.82
12.0	1.2	24.06	20.68	8.08
14.0	1.6	24.99	21.48	8.39
15.0	1.9	25.52	21.93	8.57
16.0	2.2	26.09	22.42	8.76
18.0	2.9	27.37	23.53	9.19
20.0	3.6	28.84	24.78	9.68
22.0	4.4	30.48	26.20	10.24
25.0	5.8	32.32	27.78	10.86
30.0	8.6	34.71	29.83	11.66
35.0	11.9	36.21	31.12	12.16
40.0	15.6	36.71	31.55	12.33
45.0	19.7	36.72	31.56	12.33
50.0	24.2	36.04	30.97	12.10
55.0	29.1	35.22	30.27	11.83
60.0	34.3	34.31	29.48	11.52
65.0	39.9	33.30	28.62	11.18
70.0	45.7	32.23	27.70	10.83
75.0	52.0	31.09	26.72	10.44
80.0	58.7	29.88	25.68	10.04
85.0	65.8	30.97	26.62	10.40
90.0	73.3	32.84	28.22	11.03
95.0	81.2	34.38	29.55	11.55
100.0	89.5	34.38	29.55	11.55
105.0	98.0	33.22	28.55	11.16
110.0	106.9	31.99	27.50	10.74
115.0	115.9	31.77	27.30	10.67
120.0	125.0	31.77	27.30	10.67
125.0	134.3	31.77	27.30	10.67
130.0	143.7	31.77	27.30	10.67
133.0	149.2	31.77	27.30	10.67
134.0	151.0	37.25	32.01	12.51
135.0	152.9	39.82	34.22	13.37
136.0	154.7	39.82	34.22	13.37
137.0	156.4	36.06	30.99	12.11
138.0	158.2	31.23	26.84	10.49
139.0	160.0	26.24	22.55	8.81
140.0	161.7	21.25	18.26	7.14
140.3	162.2	19.95	17.15	6.70
144.3	168.8	0.00	0.00	0.00
BOOSTER LOADS		4518.95	3883.86	1517.64

Radiation load integration 0.0 to 144.3 sec. Sep time 140.3 MECO 432.6

Figure 11: (continued) Example of Printed Radiation Results Tables

TOTAL PLUME RADIATION FOR: (SAFETY MARGINS: MAIN-ENGINE PLUME= 1.10 AND BOOSTER PLUME= 1.25)
SCRATCH = HLLV Based BP Test - RP/O2 main engines, Solid boosters, 3 BP's
NLS HLLV Plume Radiation Trajectory with STME Out (EP55 (91-125) Sep 26 1991)

TIME (sec)	ALT (kft)	INCIDENT RADIATION RATES (Btu/sq-ft-sec) FOR POINTS SHOWN 1	3	5
0.0	0.0	32.87	29.54	13.07
5.0	0.2	33.18	29.81	13.17
10.0	0.8	34.37	30.83	14.18
12.0	1.2	35.12	31.47	14.44
14.0	1.6	36.02	32.24	14.75
15.0	1.9	36.54	32.68	14.93
16.0	2.2	37.09	33.16	15.12
18.0	2.9	38.34	34.23	15.55
20.0	3.6	39.77	35.45	16.04
22.0	4.4	41.37	36.82	16.59
25.0	5.8	43.15	38.34	17.21
30.0	8.6	45.39	40.25	18.02
35.0	11.9	46.72	41.37	18.52
40.0	15.6	47.02	41.61	18.69
45.0	19.7	46.81	41.40	18.69
50.0	24.2	46.83	41.50	19.45
55.0	29.1	52.98	47.60	26.56
60.0	34.3	61.01	55.53	35.67
65.0	39.9	63.91	58.48	36.62
70.0	45.7	62.79	57.51	36.13
75.0	52.0	60.18	55.10	34.23
80.0	58.7	56.42	51.57	31.18
85.0	65.8	54.80	49.86	28.73
90.0	73.3	53.81	48.68	26.40
95.0	81.2	52.38	47.11	23.84
100.0	89.5	49.31	44.12	20.66
105.0	98.0	45.51	40.54	17.77
110.0	106.9	43.12	38.35	17.10
115.0	115.9	41.90	37.19	17.03
120.0	125.0	40.92	36.23	17.03
125.0	134.3	39.96	35.29	17.03
130.0	143.7	39.29	34.64	17.03
133.0	149.2	39.15	34.51	17.03
134.0	151.0	44.61	39.20	18.87
135.0	152.9	47.18	41.41	19.73
136.0	154.7	47.18	41.41	19.73
137.0	156.4	43.42	38.18	18.47
138.0	158.2	38.59	34.02	16.85
139.0	160.0	33.60	29.73	15.17
140.0	161.7	28.61	25.45	13.49
140.3	162.2	27.32	24.33	13.06
144.3	168.8	7.36	7.18	6.36
150.0	178.4	7.36	7.18	6.36
432.6	361.5	7.36	7.18	6.36
TOTAL RAD LOADS		8779.82	8040.66	4900.47

Radiation load integration 0.0 to 432.6 sec. Sep time 140.3 MECO 432.6

Figure 11: (concluded) Example of Printed Radiation Results Tables

Section 3
LIMITATIONS AND RESTRICTIONS

3.1 Geometry

Assumptions made in selecting ground rules for the vehicle geometry and trajectory descriptions provide a useful range of normal operations for a vehicle with strap-on boosters, but some "work-arounds" are necessary for other configurations and staging conditions.

Configuration dimensioning uses axisymmetric shapes for the main-stage and strap-on-booster geometries. In this initial version of the code, it is required that the stage and booster nozzle exit planes be at the same axial station. Conical and cylindrical shapes can be specified for the main-stage body and a skirt can be specified aft of the base heat shield. The boosters use the typical cylindrical body with a flared skirt. The geometry formulation assumptions do not currently allow for a cylindrical skirt or tapered boat-tail.

The propulsion arrangement is restricted to two engine specifications: one for main-stage engines and one for booster engines. The main-stage engine arrangement is described by an inner and outer engine mounting circle with uniformly spaced engines, and the booster engine arrangement is restricted to two to four strap-on boosters.

Because of changes in configuration and engine arrangement associated with staging, several restrictions are placed on the use of the code, but most cases of current interest can be evaluated by piecing together results obtained with separate configurations for the first- and second-stage portions of the trajectory. Requirements for this procedure result from the following characteristics of the current code:

1. There is no distinction in treatment of main-stage and booster body points to allow termination of heating to booster body points at separation.
2. Although the radiation code recognizes the change in plume configuration at separation of the strap-on boosters, the convection portion of the code does not. As a result, main-stage body points must be handled separately for the convection results.
3. There is no provision for treatment of some of the main-stage engines as boosters which separate.
4. There is no provision to handle sequential separation with altitude starts of separate successive stages.

Possible methods for operating the code to work around these characteristics are described in the balance of this section on geometry. Heating to booster body points can be evaluated by using a modified trajectory with the Main Engine Cut-Off (MECO) time set equal to the booster separation time (or the end of shutdown spike radiation for Solid Propellant Boosters). This will provide the correct upper time limit for terminating integration of the heating for the boost stage.

The use of the modified trajectory can also allow producing a boost-only result which can be used to represent either the convective heating configuration to main-stage body points before separation or a change in main-stage propulsion reflecting staging a portion of the main engines.

The division in trajectory suggested above assumes that the main-stage engines used in second stage operate at a chamber pressure which is high enough to start the sustainer engines at sea level and obtain results through both first and second stage. Then the boost portion of the results can be deleted and replaced with the first-stage results obtained as described previously.

The code was designed with the assumption that flight would begin at sea level, so it not expected to operate with initiation at higher altitudes. If a problem involves drastic changes in chamber pressure and/or area ratio, as occurs in sequentially staged vehicles, the nozzle exit pressure at sea level may not be high enough to initiate an upper stage at sea level as the logic in the current code expects.

3.2 Convection

The convective heating routines process one engine configuration on each execution. To obtain results for separate first- and second-stage engine arrangements requires use of the strategies described previously in Section 3.1.

3.3 Radiation

Radiation from booster and main-engine plumes is computed separately in order to allow the booster plume radiation to be terminated at staging. This prediction procedure is conservative, because absorption of radiation from plumes of one stage by plumes of the other stage is neglected.

If body points are on the main stage, integration of the booster radiation will stop at separation, or in the case of SRM boosters, at the end of the shutdown spike. However, body points on the booster portion of the structure must be run with a trajectory file using MECO=separation time as described previously. Explicit safety margins for the main engines and booster are added in subroutine `rad_rates_out`. These can be modified by the user.

3.3.1 H_2/O_2 Plumes

In order to reduce compute time, band-model predictions for O_2/H_2 use a spectral band of 2600 to 4600, and the results are multiplied by 2.86 to simulate the full spectrum. This is expected to approximate sea-level rates and over-predict rates at higher altitudes. The spectral interval is specified in subroutine initial (file `band_model.f`), and the limits can be adjusted by the user within the limits available in the `h2o.400` file of band-model data. Evaluation of the spectral band approximation is included in Ref. [1].

3.3.2 SRM Plumes

SRM rates at sea-level are determined using a 15 degree, cone-frustum model with 10 axial, equal-length nodes one nozzle-exit-radius long. This geometric model and emissive powers assigned to each node are based on predictions for the Space Shuttle SRM boosters with three different propellants: the normal SRM [2] with 16 percent Al, 69.7 percent AP and a PBAN binder; the Advanced Solid Rocket Motor (ASRM) [3] using a propellant with 19 percent Al, 68.9 percent AP and an HTPB binder; and an approximation with 21 percent Al. Because of the difference in binder fractions, the extrapolation based on Al is exaggerated, and attempts to make predictions at 21 percent Al were extremely sensitive to assumptions made concerning the binder fraction. However, the binder fraction used for the ASRM is expected to be near the minimum for future work. Limits of the extrapolation are set at factors of 0.5 to 2.0 times the 16 percent emissive powers, so extreme aluminum fractions will not show expected trends. The emissive power and extrapolation coefficients are described in Ref. [1], and they appear as data in subroutine `srm_radiation` if the user desires to examine or adjust the data.

Large changes in SRM booster chamber pressure are not expected, so large nozzle-area-ratio changes are also unlikely. Increasing chamber pressure tends to increase plume size, but the higher expansion ratio tends to reduce the plume temperature. The SRM plume model is based on data for an SRM chamber pressure of 750 psia, and no adjustment is made in the sea-level plume emissive power for chamber pressure. Evaluation of ASRM (19 percent aluminum) predictions at chamber pressures of 750 and 870 psia [4,5] indicated a mixed trend in plume emissive powers depending upon axial position. The average change was only −0.022 percent although individual node emissive powers varied from −3.8 to +8.1 percent. Because of the small and uncertain chamber pressure effects, no adjustment is made for chamber pressure. As a result, use of the code with extreme chamber pressures is not expected to give correct trends. Although the sea-level model is not sensitive to chamber pressure, the altitude adjustment is based upon Pc/P_{alt} to reflect effects of trajectory and chamber-pressure profile.

Because the code is only expected to be applied to relatively large SRM boosters, no effect of scale was included in sea-level or altitude parameters. If small plumes are considered, the emissive powers may tend to be less because of the reduced optical depth, but dynamics of the flow in small motors tend to increase nonequilibrium between the particles and gas which generally increases particle temperatures at the same relative locations in the near plume.

3.3.3 RP/O_2 Plumes

It is not possible to handle RP/O_2 plumes with band-model predictions because the chemistry codes used for plume prediction do not model the soot production resulting from the combustion process. As a result, a viewfactor model is used for RP/O_2 plumes. The plume model is based on an approximation of experience on the Saturn S-IC stage, but the trends are difficult to generalize. The plume model is identical to the first portion of the Saturn S-IC model [6], but no data were available comparing predictions of this plume to flight experience. The trends with altitude shown in Ref. [6] illustrate the range of behavior noted as a function of location in the base. The radiation is high at sea-level, then is roughly constant with increasing altitude until reversal for the plume gases begins. This increase in proximity of hot, highly emitting gases in the base region causes a radiation hump. The ratio of the hump to sea-level rates depends upon base location, but generally, rates which are low at sea level get a larger relative increase. This is modeled by using two altitude adjustment curves, with selection based on the sea-level rate being above or below 7 Btu/ft^2-sec. This is relatively arbitrary and the user may have to use judgment in evaluating the results.

No experience is available for varying the sea-level plume model with chamber pressure. The F-1 engine on the Saturn S-IC stage had a chamber pressure of 965 psia and a nozzle area ratio of 16. The turbopump exhaust gas was injected into the nozzle at an area ratio of 10 and formed a very sooty, low-energy mantle of gas around the plume which significantly affects the characteristics of the radiation model used. The plume model used for the H-1 engine on the Saturn S-I stage was not significantly different from the F-1 model [6]. Both have a short initial section modeling the radiation before afterburning begins, then a long cylindrical section. The H-1 engine was smaller, with a nozzle area ratio of 8 and chamber pressures of 580 to 690 in various versions. The turbopump exhaust was not dumped into the nozzle, but some outboard engines were fitted with "aspirators" around the nozzle which were used to dispose of the turbine exhaust. The plume radiation model used without the aspirator had a slightly hotter initial section because of the lack of absorption by the turbine exhaust, but downstream of the point at which afterburning starts, the plume-model emission is similar on the F-1 and H-1. The H-1 plume model had a cylindrical section with a dimensionless radius (divided by Re) 15 percent larger than the H-1 which may be attributed to a higher nozzle exit pressure.

Section 4
CODE INSTALLATION REQUIREMENTS

4.1 Computer Hardware/Software

The code was developed on a SUN 4 system using both FORTRAN and C programming languages. Although no portability tests were made, it is anticipated that the code could be ported to a compatible UNIX system using an X11r5 (X11 Release 5) window environment with Xview libraries.

4.2 Code Structure and Assembly

The code consists of three executable modules — `als`, `radiation`, and `conv_base_htg` — in a suitable directory arrangement. The directory structure used in development is shown in the diagram on the following page. The code home directory is defined as ALSHOME in the owner's `.userrc` file, and the code makes use of this environment variable in locating the data directory. The `samples` directory can be used for initial familiarization with the code, but the user can execute the code from other directories outside the ALSHOME directory structure. However, if the default trajectory files are to be used, they must be moved to the directory from which the code is executed.

The code can be compiled, assembled and installed using the Makfefile furnished in each source-code subdirectory.

```
#-----------------------------------------------------------------------------
#
#     ALS BASE HEATING CODE INSTALLATION OUTLINE
#    REMTECH, Inc. - November 1992
#
#-----------------------------------------------------------------------------
# DIRECTORY AND EXECUTABLE ARRANGEMENT
#-----------------------------------------------------------------------------
#              SUBDIRECTORIES
#     |        +--bin-----als*          <-- executables - als executes
#     |        |          radiation*                      radiation and
#     |        |          conv_base_htg*                  conv_base_htg
#     |        |
#     |        +--samples               <-- data & results for sample
#                                           problems
#     |        |
#     | ALSHOME +--alsrad--[radiation*]  <-- linked here, installed in bin
#     |DIRECTORY|         alslib.a          radiation requires alslib.a
#     |        +--band----bandlib.a                             bandlib.a
#     |        +--ravlib--ravdvllib.a                           ravdvllib.a
#     |        +--veclib--f773dlib.a                            f773dlib.a
#     |        |
#     |        +--conv----[conv_base_htg*]<-- linked here, installed in bin
#     |        |
#     |        +--window--[als*]         <-- linked here, installed in bin
#     |        |
#     |        +--data                   <-- plume data for radiation
#-----------------------------------------------------------------------------
# INSTALLATION INSTRUCTIONS
#-----------------------------------------------------------------------------
#
# define in the owner's .userrc file
#     export ALSHOME=this directory
# to check for properly installed
#     echo  $ALSHOME
#
# Execute the Makefile in the ALSHOME
# directory using the following commands
# after the users prompt (user>):
#
# To make and executables in the source directories, use
# user> make all
# or
# user> make debug
# To install the executables in the bin directory
#
# user> make install
#
# To remove objects and executable copies in the source directories
# user> make clean
#-----------------------------------------------------------------------------
```

Section 5
REFERENCES

[1] Bender, R. L., Reardon, J. E., Somers, R. E., Fulton, M. S., Smith, S. D., and Pergament, H., "Base Heating Methodology Improvements," REMTECH RTR 218–01, Vol. I, Nov. 1992.
[2] Greenwood, T. F., "Orbiter/SSME Operational Base Heating Environments," MSFC Memo ED33-84-32 to L. K. Zoller, July 3, 1984.
[3] Reardon, J. E. and Everson, J. E., "ASRM Cycle 1 Plume Radiation Methodology," REMTECH RTN 213-09, Feb. 28, 1991.
[4] Reardon, J. E., Everson, J., and Smith S. D. (SECA, Inc.), "Analytical Methodology for the Cycle 1.5 ASRB Plume Radiation Predictions," REMTECH RTN 250-02, Oct. 30, 1991.
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[6] Mullen, C. R., et.al.,"SATURN Base Heating Handbook," The Boeing Company, NASA CR-61390, May 1, 1972.